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# Analysis of the relationship between quality of the water from surface springs and occurrence of waterborne diseases in the state of Rio Grande do Norte, Brazil

## *Análise da relação entre a qualidade da água de mananciais superficiais e a ocorrência de doenças de veiculação hídrica no estado do Rio Grande do Norte, Brasil*

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**ABSTRACT**: Water characterization through indices consisting of characteristics that can be measured through the analysis of physicochemical and microbiological parameters is useful in environmental surveillance, as well as in the interpretation of possible health risks linked to the use of contaminated water, in addition to contributing to defining the environmental management actions required for water conservation. The objective of this study was to evaluate, through water quality (WQI) and trophic state (TSI) indices, the influence of the quality of public water supply in the state of Rio Grande do Norte on the occurrence of waterborne diseases (WBDs) in its population in seventy municipalities from 2008 to 2016. A hierarchical cluster analysis was performed with the intention of classifying the municipalities, based on the quality of the water consumed and represented through the aforementioned indices. In addition to that, a generalized linear model was used to describe the influence of water quality on the occurrence of WBDs. A geospatial analysis was performed with the objective of describing the priority areas in sanitary relevance causal order. Five clusters were created according to the water quality pattern observed. The Piranhas-Açu and Apodi-Mossoró hydrographic basins were the ones that presented the largest number of municipalities containing springs with the worst indices in terms of water quality and frequency of WBDs during the period under study. A statistically significant difference was established between the water quality found and occurrence of waterborne diseases. Odds Ratio for contracting WBDs up to 5 times higher than those found in places with better water quality were documented. Thus, the findings of this research highlight the usefulness of studying environmental quality, mainly for delineating priority areas for the implementation of environmental and health policies aimed at minimizing the impacts of poor environmental quality on the health of the population.

*Keywords*: waterborne disease; water deficit; water quality indices; environmental health; sanitation.

**RESUMO**: A caracterização hídrica mediante índices compostos por características mensuráveis através da análise de parâmetros físico-químicos e microbiológicos é útil na vigilância ambiental, bem como na interpretação de possíveis riscos sanitários atrelados ao uso de água contaminada, além de contribuir para definir as ações de gestão ambiental necessárias à conservação hídrica. Este trabalho objetivou avaliar, por intermédio de índices de qualidade de água (IQA) e de estado trófico (IET), a influência da qualidade da água de abastecimento público no estado do Rio Grande do Norte sobre a ocorrência de doenças de veiculação hídrica (DVHs) de sua população em setenta municípios no período de 2008 a 2016. Uma análise de conglomerado (cluster) hierárquico foi realizada com o intuito de classificar os municípios, baseando-se na qualidade da água consumida e representada através dos índices supracitados. Além disso, um modelo linear generalizado foi utilizado para descrever a influência da qualidade hídrica sobre a ocorrência de DVHs. Uma análise geoespacial foi realizada com o objetivo de descrever as áreas prioritárias em ordem causal de relevância sanitária. Cinco conglomerados foram construídos segundo o padrão de qualidade hídrica observada. As bacias hidrográficas do Piranhas-Açu e do Apodi-Mossoró foram as que apresentaram o maior número de municípios contendo mananciais com os piores índices de qualidade e frequência de doenças de veiculação hídrica no período estudado. Uma relação estatisticamente significativa entre a qualidade hídrica encontrada e a ocorrência de doenças de veiculação hídrica foi estabelecida. Razões de chance de adoecer de até mais de 5 vezes do que as encontradas em locais com melhor qualidade hídrica foram documentadas. Desta forma, os achados desta pesquisa salientam a utilidade do estudo da qualidade ambiental, principalmente para o delineamento de áreas prioritárias para implementação de políticas ambientais e sanitárias dirigidas à minimização dos impactos de uma má qualidade ambiental sobre a saúde da população.

*Palavras-chave*: doença de veiculação hídrica; déficit hídrico; índices de qualidade da água; saúde ambiental; saneamento básico.

## 1. Introduction

Water quality is a determining factor for social and economic development of societies (Abbasnia et al., 2019). Thus, in regions with water shortage, there may be water quality impairments and, consequently, environmental sustainability problems (Vanham *et al.*, 2018). Added to this, absence of basic sanitation can exert negative effects on the population's health (Pandit, 2013; Zhang et al., 2021).

In Brazil, more than 34 million people have no access to drinking water and only 46.2% of the Brazilian population has sewage collection services (Trata Brasil, 2021). In 2017, for example, the incidence of hospitalizations due to diseases associated with non-sanitation corresponded to 12.46 for every 10,000 inhabitants, with the Brazilian Northeast as the region with the highest rates (Trata Brasil, 2018). In this sense, added to the sanitation deficit, water shortage represents a problem.

The delimitation of the Brazilian Semiarid area is mostly concentrated (89.5%) in the Northeast Region, covering most of the northeastern states (IBGE, 2018), where rainfall presents time and spatial irregularities and, as a consequence, it is common to see periodic shortages in times of more critical droughts. In this setting, it poses a permanent risk for the supply of rural families, who depend on the natural resource for survival (Mattos & May, 2020). In addition to that, the semiarid region requires special attention, as its climatic characteristics converge in a scenario imposing potential additional risks on public health through the occurrence of waterborne diseases (Chaves *et al.*, 2019).

It is and indispensable task to learn about the quality of the water from a given water body in order to adequate it to its most varied uses, be them for consumption or not (Brazil, 1997; ANA, 2021). In the Brazilian Semiarid area, this need is even more indispensable, as water availability is limited by the high rates of evapotranspiration of water bodies that exceed the rainfall ones, added to the current occurrence of one of the most severe droughts in the last 50 years (Cunha *et al.*, 2018). Therefore, water quality monitoring is a fundamental activity to minimize risks to human health (Renouf *et al.*, 2017).

Several water quality indices have been developed to understand it, as they are easily accessible tools for simple and efficient dissemination of results (Ferreira *et al.*, 2015; Zotou *et al.*, 2020). One of the indices widely used in Brazil is the Water Quality Index (WQI), which was developed in 1970 by the National Sanitation Foundation (NSF) and resorts to the following parameters: Dissolved Oxygen, Thermotolerant Coliforms, pH, BOD5, Total Nitrogen, Total Phosphorus, Turbidity, Total Solids and Temperature.

In addition to that, another frequently applied index is the Trophic State Index (TSI), which was developed by Carlson (1977) and improved by Toledo Junior *et al.* (1983) and Lamparelli (2004) and that, as adopted by the Environmental Company of the State of São Paulo (Companhia Ambiental do Estado de São Paulo, CETESB, 2007), uses the concentration of total phosphorus and chlorophyll ‘a’ to determine the trophy degree of water. These indices integrate a limited number of physical, chemical and microbiological characteristics, making them easy-to-implement and easy-to-apply tools to describe both water quality and the consequences resulting from water body pollution (Andrietti *et al.*, 2016).

In this sense, the state of Rio Grande do Norte (RN) – which, of its 167 municipalities, 147 are located in the Semiarid area (IBGE, 2018), is the object area of this study – and presents a considerable part of its public water supply springs with a history of eutrophication, with annual variations described by cyanobacterial blooms, including potential toxin-producing species (cyanotoxins) in its waters, especially in the dry period. This phenomenon is enhanced with the reduction of its stored volumes and consequent increase in the concentration of nutrients in water and in rainy periods, when there is no spillage and renewal of its waters (Bezerra *et al.*, 2014; Moura *et al.*, 2018). In RN, a total of 553,000 inhabitants (16.25%) do not have access to drinking water (Brazil, 2020) and the Water Treatment Plants (WTPs) of the state are mostly of the conventional type and may not completely remove cyanobacteria/cyanotoxins, which may remain in the distributed water and cause harms to the nervous system and liver, among other organs, originate tumors and even cause death (Albuquerque *et al.*, 2020).

Spring waters also receive pollutant loads from anthropogenic activities, which may contain pathogenic microorganisms such as protozoa, viruses and bacteria, thus causing health consequences to the population, called Waterborne Diseases (WBDs) (Araújo *et al.*, 2013; Nascimento *et al.*, 2013; Reddy & Dubey, 2019). Given all of the aforementioned, WBDs are a health problem, and the Unified Health System (Sistema Único de Saúde, SUS) provides updated information about the occurrence of different diseases, including WBDs. However, there is scarcity of studies relating water quality to occurrence of WBDs.

Therefore, given the above, the current paper aimed at analyzing the water quality of important surface springs for public supply located in Rio Grande do Norte through the values reported for the WQI and TSI indices, considering their influence area as water sources and their relationship with the occurrence of WBDs.

## *2. Methodology*

### *2.1. Study area characterization*

The state of Rio Grande do Norte (RN) is located in the Brazilian Northeast region and, according to the Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatística, IBGE, 2021), has an estimated population of 3,560,903 inhabitants distributed among its 167 municipalities and a territorial area of 52,811.107 km², consisting of sixteen (16) water basins (IGARN, 2014) where reservoirs were built aiming to ensure water supply regularization, especially as a strategy for coexistence in drought periods.

Nearly 90% of the RN territory presents semiarid climate characteristics. Thus, rainfall distribution is typical of the area and varied from the space-time perspective (Silva & Lucio, 2015). In the coastline of the state of RN, maximum rainfall is in June, whereas the West region that is part of the semiarid area presents humid climate aspects, thus presenting regular rainfall. The central region, which is also part of the Semiarid area where the Seridó is located, is the region that most suffers frequent droughts (Santos and Silva *et al.*, 2012).

### *2.2. Databases used*

The information on water quality through WQI and TSI in the period from 2008 to 2016 was extracted from the *Água Azul* (Blue Water) Program (2016), which was created by the RN State Government in partnership with higher education institutions. Of all sixteen (16) water basins in the state, seven (07) have water bodies monitored by this program, namely: Apodi-Mossoró, Ceará-Mirim River Basin, Jacu, Maxaranguape, Piranhas-Açu, Potengi and Trairí river basins, which include collections in seventy (70) municipalities that have important springs for public supply.

The WQI consists of a scale with values from 0 (zero) to 100 (one hundred) where the higher the value, the better the quality of the water in question. In turn, the values are classified as follows: Extremely deficient (WQI < 25); Deficient (25 ≤ WQI < 50); Average (50 ≤ WQI < 70), Good (70 ≤ WQI < 90) and Excellent (90 ≤ WQI ≤ 100), according to WQI-NSF. The trophy degree is assessed by classifying natural waters using the TSI (CETESB, 2007), which ranges from Ultraoligotrophic (TSI ≤ 47), Oligotrophic (47 < TSI ≤ 52), Mesotrophic (52 < TSI ≤ 59), Eutrophic (59 < TSI ≤ 63) and Supereutrophic (63 < TSI ≤ 67) to Hypereutrophic (TSI > 67), the latter representing the classification that characterizes a spring with a very high trophy degree.

The information on waterborne diseases was collected from the locations where the *Água Azul* Program monitored the period mentioned in the electronic database belonging to the Unified Health System present in the Primary Care Information System (*Sistema de Informação de Atenção Básica*, SIAB) of the Unified Health System Informatics Department (DATASUS), available on its electronic portal - www.datasus.gov.br - in the period covered by this research. The diseases cataloged as WBDs according to the Ministry of Health (MS, 2015) include the following: cholera, typhoid and paratyphoid fevers, shigellosis (bacillary dysentery), amoebiasis, diarrhea, gastroenteritis and other intestinal infectious diseases, of higher prevalence in the population of the municipalities where the water bodies are located).

### 2.3. Statistical analyses

The geospatial analysis of the data collected was performed in Qgis 3.16.5. In addition to that, a descriptive multivariate analysis was performed using the hierarchical cluster analysis method and considering the TSI and WQI variables. The resulting classification based on the water quality described by the aforementioned indicators was used to analyze the effect of the reservoirs' water quality on the WBD profile. Two distributions were tested: normal and gamma. The model's adherence was assessed through the Akaike Information Criterion (AIC). All the statistical analyses were performed in *SPSS Statistics* version 26 (*Statistical Package for the Social Sciences*).

## 3. Results and discussion

The results herein presented were based on the analysis of the available information from 70 (seventy) municipalities with springs monitored by the Água Azul Program (2016). Figure 1 shows the Water Quality Index – WQI. More than 80% of the results fell into the "Average" classification. Only 18% of the results from this index were considered within the "Good" category.

The Extremoz Lagoon located in the municipality of Extremoz was one of the water bodies with WQI considered "good" in the period under study, a result congruent with the one reported by the study by Jeronimo & Souza (2013) carried out between 2011 and 2012 in the same town, ratifying the result described. The worst quality reported and classified as "Deficient" in the period under study corresponded to a water body located in Mossoró, one of the most densely populated municipalities in that state.

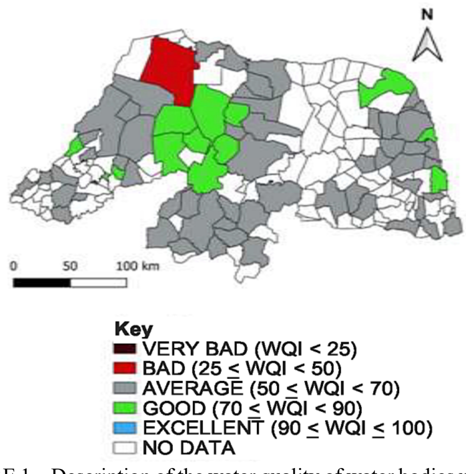


FIGURE 1 – Description of the water quality of water bodies used for human supply by means of WQI results reported in the 2008-2016 period (map of Rio Grande do Norte state, Brazil).

SOURCE: Prepared by the authors.

It is worth mentioning that, in the state of RN, there is predominance of water supply service provision by the State Water and Sewage Company (*Companhia Estadual de Água e Esgoto*, CAERN), which in most municipalities operates provision of these services from regionalized systems that transport water over long distances to supply the population of municipalities with water scarcity problems in local reservoirs. At the time of this study, in 2014, Rio Grande do Norte ranked 12th in Brazil in terms of household water supply, with 82.73% coverage; and 2nd in the Northeast, immediately after Sergipe (85.11%) and before Paraíba (80.66%) (Brazil, 2016). As previously mentioned, there is still a large part of the population – more than 500,000 people – without access to drinking water and, even when the raw water from the springs goes through the treatment processes, as they are conventional WTPs, some agents may not be completely removed and/or there is contamination during water distribution. Thus, contamination and the increase of toxic substances in water and vectors of waterborne diseases are directly related to basic sanitation and inadequate water treatment conditions (Nova & Tenório, 2019).

The water quality degree can also be analyzed through the TSI, which represents the eutrophication level, linking the potential nutrient load received by a water body to the factual effect of plant growth. Of the total water bodies analyzed, according to Figure 2, 4.3% (3 municipalities) were ultraoligotrophic, 20% (14 municipalities) were oligotrophic, 38.6% (27) of the municipalities presented, in the period from 2008 to 2016, water bodies considered "mesotrophic", 20% (14 municipalities) were "eutrophic", almost 13% (9 municipalities) fell into "supereutrophic" and 4.3% (3 municipalities) presented water bodies with TSIs considered "hypereutrophic".

The interpretation of TSI and WQI can relate water quality to hints of water contamination caused by anthropic actions linked to deficient sanitation, such as lack of access to simple hygiene measures, discharge of untreated domestic effluents into water bodies and inadequate disposal of waste, among others (Rocha *et al.*, 2021).

A number of studies about the environmental quality of water resources have shown the relationship between the eutrophication level and the potential health consequences (Viviani, 1992; Clark *et al.*, 2017). For example, eutrophication levels in the "eutrophic", "supereutrophic" and "hypereutrophic" categories have been associated with the occurrence of microorganisms (cyanobacteria) producing toxic substances (cyanotoxins) (Yokoyama & Park, 2002; Kokociński *et al.*, 2010; Sinha *et al.*, 2018).

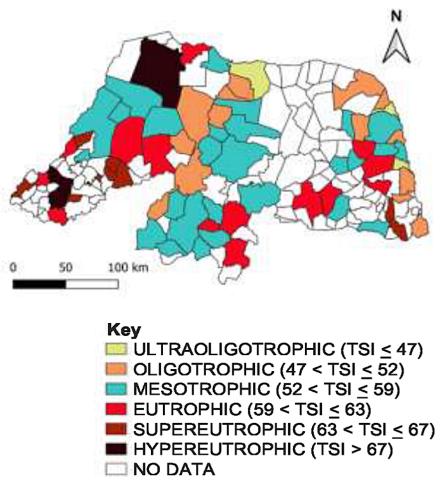


FIGURE 2 – Description of the water quality of water bodies used for human supply by means of TSI results reported in the 2008-2016 period (map of Rio Grande do Norte state, Brazil).

SOURCE: Prepared by the authors.

The main poisoning route for cyanotoxins is oral water consumption. However, poisoning can also occur through recreational contact in a water body or even due to eating contaminated fish. Another exposure route, though less common, is using showers (inhalation route) and, exceptionally, through hemodialysis (intravenous route) (Almeida *et al.*, 2015). Thus, the presence of these cyanotoxins in human water supply implies serious risks to public health, as they are soluble in water and can pass through the conventional treatment system (Rodrigues *et al.*, 2021).

Drinking water contaminated with these toxins can bring about countless consequences. As a representation that, although less frequent, has significant importance in public health, there is the case in a clinic from the city of Caruaru (PE) where, 116 chronic renal patients started to present a clinical condition compatible with severe hepatotoxicosis after having undergone hemodialysis sessions in 1996. Of them, 54 evolved to death up to five months after onset of the symptoms. Laboratory analyses enabled isolation and detection of the Microscitin-LR cyanotoxinin the clinic's water purification system, as well as in blood and liver samples from the intoxicated patients (Carmichael *et al.*, 2001; Libânio, 2010).

The municipality of Mossoró is one of those that presented a water body with a TSI classified as “hypereutrophic” (Figure 2), a fact that can be justified by natural environmental conditions, in which alluvial sediments practically cover the entire area of direct influence of the geological-geomorphological processes in the Apodi-Mossoró River, making the soil highly porous and permeable, susceptible to erosive processes and siltation of watercourses, as well as contamination of surface and groundwater bodies. However, sanitation deficits and anthropic activities alike play a fundamental role in the pollution and eutrophication of water resources. For example, a study conducted by Petta *et al.* (2010) described the anthropic influence on eutrophication of the Apodi-Mossoró river in the aforementioned municipality. The causes cited were production of solid waste and effluents as well as disorganized use and occupation, mainly on the watercourse banks, thus contributing to aggravation of the environmental impacts suffered, facts that can justify the hypereutrophication described and ratified in this paper.

Water is one of the largest vectors for the dissemination of toxic substances and microorganisms, with the possibility of affecting the population's health at an epidemiological scale (Trujillo, 2016). The World Health Organization (WHO) indicates that a high percentage (88%) of deaths due to waterborne diseases worldwide have been linked to factors related to poor quality of the water consumed throughout life and caused by inadequate sanitation (Trata Brasil, 2021).

According to the Trata Brasil Institute data platform, in 2018, nearly 233,000 cases of diseases associated with lack of sanitation were recorded in the country, corresponding to an incidence of 11 hospitalizations for every 10,000 inhabitants, causing 2,180 deaths and expenses of approximately R$ 90 million for the Brazilian health system (Trata Brasil, 2021). Diarrhea is the second leading cause of death in children under 5 years of age (84%), according to the United Nations Children's Fund (UNICEF). According to DATASUS data, in Rio Grande do Norte the hospitalization rate due to diarrhea alone was 113.7 for every 100,000 inhabitants between 2000 and 2015. Therefore, several diseases are aggravated due to contact with unhealthy environments.

In this sense, according to data from the National Sanitation Information System (Sistema Nacional de Informação sobre Saneamento, SNIS), approximately 35 million Brazilians lack access to drinking water and 100 million inhabitants do not have access to domestic sewage collection services. In addition to these indicators, Brazil still has certain difficulty with sewage treatment, where only 50% of the volume generated is treated, that is, a large part of what is not treated is dumped into nature everyday (Brazil, 2020) in the most diverse receiving bodies that, in addition to soil, can be springs – the same ones used to collect water to supply the population, a fact that can have countless ecological and health implications (Costa *et al.*, 2018).

Thus, the occurrence of waterborne diseases is a relevant public health problem in Brazil. The following WBDs were addressed in this paper, considering that they can be linked to lack of access to sanitation and consequent eutrophication, namely: cholera, typhoid and paratyphoid fevers, shigellosis (bacillary dysentery), amoebiasis, diarrhea and gastroenteritis, in addition to other intestinal infectious diseases, in the period herein covered and considered. Even though dengue is considered a waterborne disease according to the Brazilian Ministry of Health, it was not included in this study because it is an arbovirus vectored by mosquitoes and not directly by drinking and/or contact with water.

Based on the diseases listed, the state of Rio Grande do Norte presented 3,228,198 cases (WBD incidence of 94,947.0 cases for every 100,000 inhabitants) during the period under study. At the national level, WBDs were responsible for 2.35% of all hospitalizations in Brazil, generating 0.7% of the total SUS expenses related to hospitalizations in 2015. Of these hospitalizations, 43.4% corresponded to individuals aged at least 10 years old (Paiva & Souza, 2018). Figure 3 shows the spatial distribution of the number of WBD cases during the period under study (2008-2016), by municipality.

Of the 70 municipalities under study, 41.4% (29) recorded up to 245 cases in the period between 2008 and 2016, 20% (14) recorded between 763 and 1,455 cases, and only one municipality (Caicó) recorded between 2,763 and 3,821 cases of WBDs in the period studied. Even if this figure is overestimated due to the fact that the hospital in this city receives cases from other towns and even from other states, these additional cases mostly come from surrounding cities that receive the same water resources and, therefore, have similar sanitation and water quality conditions.

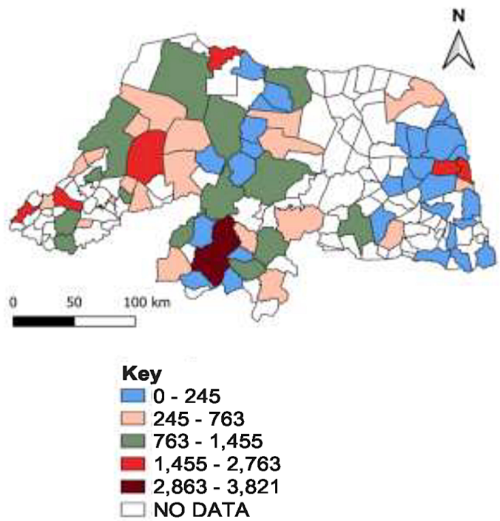


FIGURE 3 – Absolute frequency of hospitalizations (2008-2016) due to WBDs, per municipality under study (map of Rio Grande do Norte state, Brazil).

SOURCE: Prepared by the authors.

It is interesting to note that the municipality of Caicó (3,821 cases and prevalence of 60.10 cases for every 100,000 inhabitants) presented the highest absolute frequency in the state. In a previous study conducted by Nascimento *et al.* (2013) in Caicó-RN, it was verified that this municipality also presented higher prevalence of hospitalized patients with acute diarrheal episodes, with 465 cases in 2009 (incidence of 741.52 cases per 100,000 inhabitants) and 552 in 2010 (incidence of 880.25 cases per 100,000 inhabitants), as a consequence of Waterborne Diseases.

The municipalities with higher prevalence records (burden of WBDs on the population during the period under study) can be seen in Figure 4, namely: Rafael Godeiro and Riacho da Cruz. Of the two, only Rafael Godeiro, which is part of the Apodi-Mossoró river basin, had a spring with a TSI classified in the "supereutrophic" category (TSI=65) during the period under study.

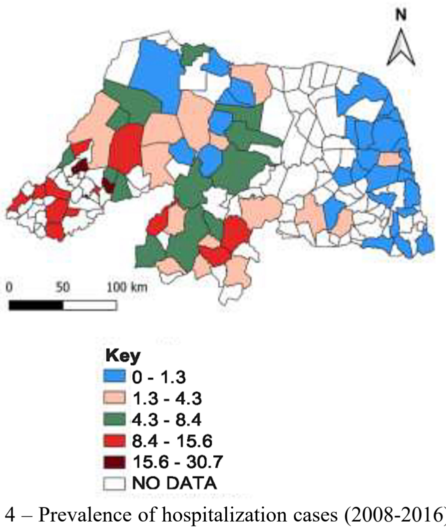


FIGURE 4 – Prevalence of hospitalization cases (2008-2016) due to WBDs, by municipality under study (map of Rio Grande do Norte state, Brazil).

SOURCE: Prepared by the authors.

In the map showing the prevalence of hospitalizations due to WBDs (Figure 4) it can be seen that there was emphasis in the region that covers the municipalities of Marcelino Vieira (TSI=70) and Pau dos Ferros (TSI=69) (hypereutrophic), Pilões (TSI=67) and São Miguel (TSI=64) (supereutrophic), and also Tenente Ananias (TSI=63) and Encanto (TSI=61) as municipalities with average eutrophic TSIs for the period under study. These values may ratify a possible relationship between the trophy degree of the water bodies and the cases of WBDs contained in this study, which indicate high cyanobacterial activity, which kept the TSI high during the period and may have caused health impacts on the population consuming the waters from these springs.

To understand the influence of water quality represented by the WQI and the TSI, a hierarchical cluster analysis was performed on the seventy (70) sites monitored and where the springs are located, as shown in Figure 5.

A total of five (5) clusters were defined for the classification of the municipalities, as illustrated in Figure 6. Thus, conformation of the municipalities with Cluster 1 mostly (13/15) corresponded to the Apodi-Mossoró River Water Basin (WB). Most of these municipalities presented water bodies with average water quality (WQI) and at least eutrophic trophy degree, which is already a risk, varying to hypereutrophic as in the cases of Marcelino Vieira (TSI=70) and Pau dos Ferros (TSI=69). These municipalities presented a considerable prevalence of WBDs, as in the case of Rafael Godeiro (TSI=65, which is supereutrophic and prevalence of WBDs = 30.7/10,000 inhabitants), reinforcing the hypothesis that water quality may be generating health risks to the population of these towns.

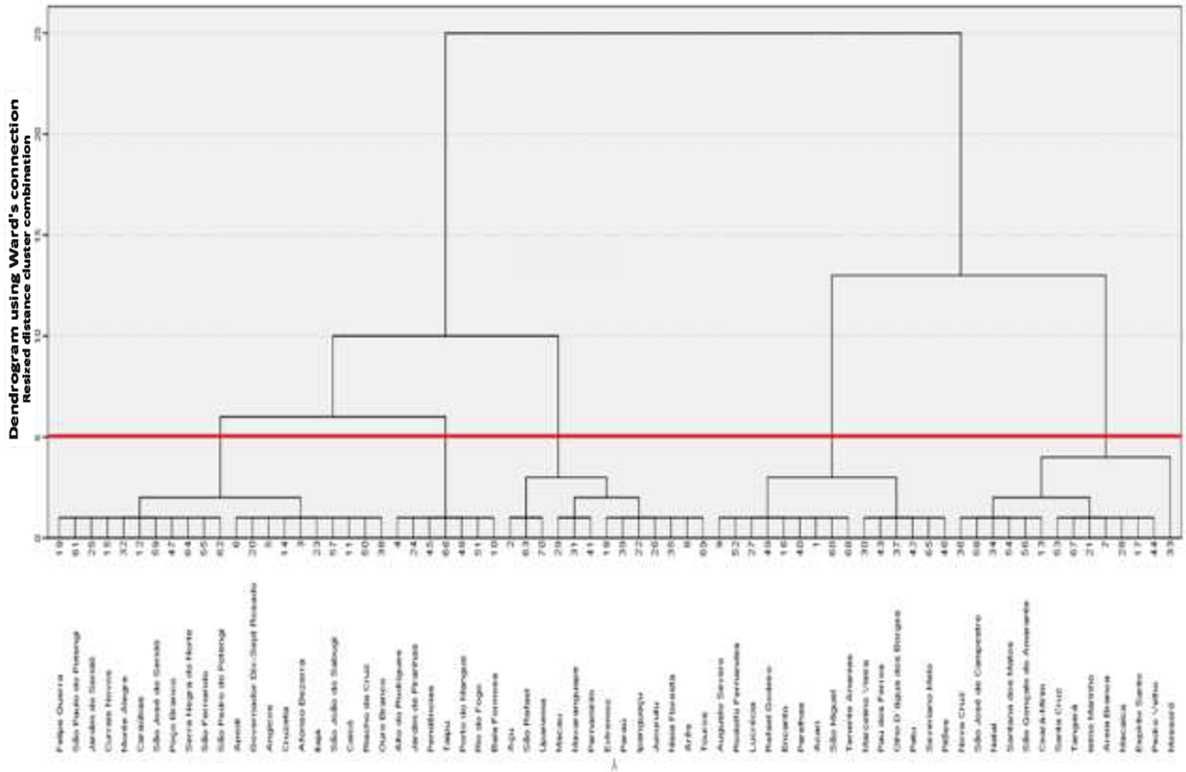


FIGURE 5 – Hierarchical cluster analysis. Ward's method for the municipalities based on the water quality described by means of the TSI and WQI indices.

SOURCE: Prepared by the authors.

In turn, Cluster 2 (13 municipalities) was comprised by municipalities from all 7 water basins analyzed and mostly presented average trophy degree (mesotrophic) and low prevalence of WBDs.

Cluster 3 (21 municipalities) was comprised by the majority of its water bodies in the municipalities of the Piranhas-Açu WB (12 municipalities), which present average WQI and trophy degrees varying from mesotrophic to eutrophic and prevalence of WBDs from average to high (considerable concerning the municipalities), a fact that again corroborates with the hypothesis of this study.

Cluster 4 consisted of 7 municipalities, with water bodies from 4 different WBs, which presented trophy degrees from oligotrophic to mesotrophic and low prevalence of WBDs, although the municipality of Jardim de Piranhas (Piranhas-Açu WB) stood out, which, even being oligotrophic, had a considerable prevalence of WBDs (10.59/10,000 inhabitants); this fact can be explained due to the Piranhas River crossing a long urban stretch where it can receive diffuse pollutant loads from agro-industrial activities, sewage, etc., which may be causing waterborne diseases in the population.

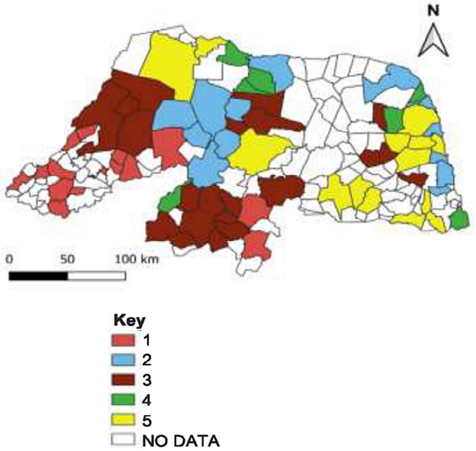


FIGURE 6 – Cluster analysis: Characterization of the areas according to the water quality found (map of Rio Grande do Norte state, Brazil).
SOURCE: Prepared by the authors.

Finally, Cluster 5 was comprised by 14 municipalities from 6 different WBs, with average WQI and TSI values varying from mesotrophic and supereutrophic (Espírito Santo, Jacu WB) to hypereutrophic (Mossoró, Apodi-Mossoró WB). In this cluster, the municipality of Areia Branca (Apodi-Mossoró WB) stands out, which was eutrophic and presented considerable prevalence of WBDs (7.65/10,000 inhabitants); as well as the municipality of Santana do Matos (Piranhas-Açu WB), which presented an average mesotrophic TSI value and WBD prevalence of 8.4 for every 10,000 inhabitants during the period analyzed. In order to understand the influence of water quality on the prevalence of WBDS, a generalized linear model was adjusted, shown in Table 1. The model with gamma distribution presented better adherence when compared to the identity distribution (Akaike Information Criterion [AIC]: 331 *versus* 423, respectively).

The water quality described by locating the springs per cluster exerted a significant influence on the prevalence of WBDs (X2: 41.62; DoF = 4; $p<0.001$). Table 1 describes the estimated parameters of the model, where Cluster 5 was considered as a reference for comparing the coefficients because it has the best water quality in the study area, as previously indicated. Regions with water classified as of average quality (Clusters 2 and 4) did not present statistically significant differences. Clusters 1 and 3 presented significant differences when compared to Cluster 5, considered as a reference. Thus, the locations included in Cluster 3 had a 2.48 times higher chances ratio when compared to Cluster 5, whereas in the locations of the municipalities included in Cluster 1 (which includes those with the worst water quality) the increase in the chances for the occurrence of WBDs was 5.20 times higher when compared to the areas with the best water quality considered as a reference.

In Brazil, from the 1960s onwards, urban areas were densified without Brazilian cities having the structural capacity to accommodate high population growth, especially in peripheral areas, where the mean increase was four times greater than in central areas. Therefore, the country consolidates itself as mostly urban (Tucci, 2009; Miranda & Gomes Junior, 2017). Above all, this fact leads to considerable environmental, social and economic pressure, as it triggers greater demand for natural resources; an increase in waste generation, soil and water contamination; and increases the deficit of basic sanitation. Therefore, all these elements generate imbalance situations that can affect vulnerable populations and contribute to the increase in the number of waterborne diseases, among others (MS, 2015).

TABLE 1 – Generalized linear model: Estimated parameters of the model.

| Parameter | B | Standard test statistics | Wald's 95% Confidence Interval | | Hypothesis test | | | Exp(B) | Wald's 95% Confidence Interval for Exp(B) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Lower | Upper | Wald's chi-square | DoF | Sig. | | Lower | Upper |
| Cluster 1 | 1.649 | 0.3655 | 0.933 | 2.365 | 20.352 | 1 | 0.000 | 5.202 | 2.541 | 10.649 |
| Cluster 2 | -0.410 | 0.3789 | -1.153 | 0.332 | 1.173 | 1 | 0.279 | 0.663 | 0.316 | 1.394 |
| Cluster 3 | 0.910 | 0.3394 | 0.245 | 1.576 | 7.197 | 1 | 0.007 | 2.486 | 1.278 | 4.834 |
| Cluster 4 | -0.128 | 0.4553 | -1.020 | 0.765 | 0.079 | 1 | 0.779 | 0.880 | 0.360 | 2.148 |
| Cluster 5 | 0 | . | . | . | . | . | . | 1 | . | . |

SOURCE: Prepared by the authors.

Based on the above, access to suitable water supply and sewage networks is an aspect of utmost importance for the population's health. Countless diseases might be prevented by investing in improvements in these networks. It is to be noted that water quality is also related to the treatment plants' operating conditions and to how treatment is carried out, which, when inadequate, produces contaminated water that is unfit for consumption, thus enabling the occurrence of waterborne diseases and complications (Guedes *et al.*, 2017).

In summary, based on the results presented and when considering the representation shown in Figure 6 corresponding to the spatial distribution of Clusters in the state of Rio Grande do Norte, it is verified that the worst indices of water quality and occurrence of WBDs were found in the West mesoregion and lower part of the Potiguar central mesoregion, in municipalities from the Apodi-Mossoró and Piranhas-Açu river basins, especially in the Seridó.

## *4. Conclusions*

Water quality is a representation of the environmental health of a given region. Water is a disseminating vector for diseases and toxic substances. Therefore, in addition to classifying water bodies, monitoring these diseases and substances even allows establishing actions related to the management of health risks. In this study, the relationship between water quality and occurrence of WBDs was analyzed and patterns of associations of these diseases with the pollution degree of surface springs used for human supply in the state of Rio Grande do Norte were found. The need for adequate water supply networks is highlighted, as water quality is also related to the treatment conditions carried out in the WTPs which, when incorrect, produce water unfit for consumption, favoring the cases of WBDs.

The state of RN still has more than half a million individuals without access to drinking water, and this reality addressed in this manuscript generates useful subsidies not only for environmental management of spring supply areas but also for managing health risks, both optimizing the available resources and minimizing the impacts of deteriorated water quality on environmental health. Finally, the need to implement monitoring programs of supply reservoirs as an environmental public policy is emphasized, as the disruption of environmental surveillance undermines the strategies applied for the benefit of health.

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